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ABSTRACT OF THE HISTORY OF THE METALLURGY
OF IRON AND THE DEVELOPMENT OF
IRON BLAST FURNACES.

BY NORMAN L. OHNSORG .

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Approved
L. Copeland.

Mankind has passed through the ages of stone, bronze and iron, and is now living in the age of steel. To the metallurgist, steel would come under the heading of iron.

Earliest historical records indicate that long previous to the date of these records, some metals were worked with rude apparatus, in an hit or miss manner.

The bible states that Tubal Cain, the great-grandson of Adam, was a worker in brass and iron.

There have been found among the ruins of ancient cities of Asia, Africa and in the copper mines and other locations of North America, implements of metal, indicating that a knowledge of metallurgy, " even tho very crude ", was possessed by the prehistoric man. According to the oldest records and traditions, the Chinese were workers of bronze and iron.

The inhabitants of the Indian Peninsula actually constructed, in metal, works now considered remarkable for their magnitude. The Chaldeans, four thousand years ago, the Persians, the Egyptians, and the Aztec inhabitants of America, if not an earlier race, had some knowledge of the manufacture of metals.

Wrought iron was produced at a much earlier date than cast iron or steel. The manufacture of wrought iron was known by several nations at a period which antedates recorded history. It was surely known in the time of Moses , 1500 B.C., as there was an iron wedge found in the Great Pyramids. It was possibly known in the time of Cheops, 3500 B.C., or possibly in the seventh Egyptian Dynasty, or still further back, in the time of Menes, 4400 B.C.

The precious metals were known at an earlier date than iron as they are more fusible and more often found in native state.

It is quite certain that wrought iron ~~and steel~~^{were} known at an earlier period than cast-iron, which seems to be a comparatively modern product.

The inhabitants of Great Britian, at the time of ^{the} discovery by the Romans, had learned to reduce iron ore in a furnace called a " bloomarie ", a simple open furnace with a blast produced, sometimes mechanically ^{and} or sometimes by a draft passage from under the hearth toward the side of the prevailing storm-winds.

The manufacture of iron by the Romans reached a much greater developement. They built at Bath a fabrica, or military forge, about 120 A.D.

The earliest masses of scoria were found on the hill-tops where furnaces were erected to obtain better air currents. These currents were admitted through holes on all sides of the furnace. After the invention of bellows, furnaces were built in the valleys. The slag from these bloomaries was rich in iron.

In these furnaces but a small quantity of ore could be worked at once, low heat^{was} obtained, deoxidation of the ore was imperfect, and work must have been exceedingly slow. The product was crude and imperfect wrought iron, as the temperature attainable was insufficient to fuse the charge, and the method of handling the reduced metal must have but imperfectly removed the slag.

This method is still practiced by natives of India, Borneo and Africa and also on ores in parts of Europe. It is called The Direct Process, to distinguish it from the modern Indirect Process, in which cast iron is first produced.

Mal^{le}able iron is the immediate result of this process. The lump of maluable iron obtained is called

a bloom.

In India, the Direct Process has been carried on from time immemorial, as large accumulations of slag are found in various parts of the country.

The furnaces used may be divided into three kinds: first, those employed in western part of India and through the Decan. This is the rudest form and is used by the less civilized people; the second and third kind, used in Central India and in the North West Provinces, resemble the simplest form of Catalan forge and of German Stückofen respectively. They are a higher developement than the first. The blast is produced by bellows made from the skin of a goat. Each furnace is provided with at least two such bellows, fitted with bamboo nozzles. The anvil is of wrought iron, ~~very~~ square and without a beak.

The natives of Barneo prepare their iron from a clayey iron stone which is treated in a furnace built of yellow clay, and tied around by hoops of bamboo. It's height is about three feet and it's extreme diameter about ten feet. The walls are two feet thick. It is square on the inside, narrowing toward the bottom to a rectangular hearth two feet

long and one foot wide. Each furnace has three clay tuyeres, an opening for the running off of the slag, and an external basin. Charcoal is the fuel used in the furnaces.

The blowing machine is a single acting cylinder open at the top and closed at the bottom, blast being conveyed by bamboo tubes. The piston is packed with feathers, and the piston-rod is attached to a long bamboo stick which acts as a spring, bringing the piston back again when pressed to the bottom of the cylinder. The ore preparatory to smelting is roasted in heaps, then broken in pieces the size of a nut, mixed with ten times its bulk of charcoal and charged into the furnace. When the furnace has been two thirds filled with charcoal, the mixture of ore and fuel is added in sufficient quantity to form a conical heap above the hearth mouth. About one hundred pounds of iron is obtained, which is taken out at the bottom of the furnace with wooden tongs, removed to a bed of slag, and hammered with wooden mallets.

~~The third~~ ^{Another} type of furnace is a structure of clay in the side of a mound. It's height is from eight to ten feet outside and from six to seven feet inside.

The front wall is five or six inches thick and may be readily removed. The bottom of the furnace is set at an angle of forty five degrees and on top of the bed are placed two earthen tuyeres about one and a half feet long. Fuel and ore are alternately charged to the furnace. Cinder is tapped out occasionally by pushing an iron bar in the furnace through the holes in the hearth. These holes are stopped by clay, one after another, as the iron accumulates at the bottom and rises above them. When the tuyeres are burned away by iron which has then risen to them, the process ceases. The hearth plate is removed and the mass at the bottom drops out. The bloom is usually a mixture of malleable iron and "natural" steel. Sometimes cast iron is produced and is difficult to separate from the other iron.

The Catalan Process.

This process is practiced in the North of Spain. The furnace has a rectangular hearth of refractory masonry, attached to one wall of the work-shop. Three distinct modifications of smelting hearth are used in different parts of the continent, under the names of,

Catalan, Navarrese and Biscayan forges; but as in principle, these resemble each other very closely, it will be sufficient to describe, with considerable detail, the Catalan forge, which is the chief modern representative of the ancient bloomery. The hearth of the furnace is formed in a large mass of stone, cemented together with refractory clay, or is supported on one or more arches to admit of the escape of moisture and to preserve the bottom of the hearth. On the top of the arches is a layer of fire-clay and ~~iron~~ iron slag, which is well beaten down and supports a large block of sandstone, which forms the bottom, and on this are placed the four sides of the hearth, a, b, c, d, as shown in figures one and two. The face a, which is of iron, is called the "chio", and from this side of the furnace the slags are run off. The opposite side ~~is~~ called the "cave", ¹² composed of masonry held together by refractory material, this side ¹² somewhat curved in outward direction and slightly inclined from the bottom towards the top. The side of furnace c, called the "porges" is composed of heavy iron bars placed one upon the other. The side d, known as "ore"

or "contrevent", is composed of pieces of iron having wedge shaped section and so arranged as to form a rounded surface. The tuyere N , has the form of a truncated cone, and is made by turning a piece of sheet copper into the proper shape without soldering its edges. This tuyere rests on the upper plate of the "porges" and encloses the nozzle T , by which the furnace is supplied with air, from a water blowing machine which is connected with the tuyere by leathern hose. The inclination of the nozzle materially affects the working of the furnace. In most instances it makes an angle of from 35° to 40° with the bottom of the hearth. The common dimensions are about as follows; length of hearth from "porges" to the "contrevent" a, its widest part, three feet: width of hearth from the "chio" to the face of "cave", two feet six inches: total depth, from the surface to the bottom of the hearth, two feet two inches. The distance between the "porges" and the "contrevent" at the narrowest part is twenty-seven inches. These forges are almost invariably placed on the top of a hill and are supplied with air by a water blowing machine called a "trompe", which is shown in figure one.

The hammer employed in forging weighs from twelve hundred to fourteen hundred pounds, and makes from one hundred to one hundred and fifty blows a minute. It is raised by a series of cams arranged around the axle of a water-wheel. The anvil is composed of a block of iron, fastened by a tenon on-to a large block of cast iron. The fuel used in this furnace is invariably charcoal.

The Corsican Process.

In Corsica and along the whole Mediterranean shore of Italy, a furnace very similar to the Catalan was formerly employed for direct process of malleable iron. This process at the present time has been universally abandoned. The hearth of the forge is an elongated basin on top of a platform of masonry about three feet high. The bottom was made of a mixture of charcoal-dust and clay, and the blast was supplied through an inclined copper nozzle in connection with a trompe. In this arrangement roasting, reduction and fusion were carried on, but divided into two distinct processes, one consisted in roasting and partially reducing the

ore, and the other in deoxydizing the half reduced ore. The metal was agglomerated and finally forged into bars.

The American Bloomery.

The Catalan method of iron making has been introduced in North America. The hearths are supplied with hot air through tuyeres of ordinary construction. The bottom of the hearth is of hollow cast iron plates, through which a current of cooling water circulates. The working of these furnaces is similar to the Catalan forge, the essential difference being in the method of charging. In the former, the greater portion of the charge of ore is at the commencement of the ^{process and} ~~separation~~, in large fragments against the sloping side of the hearth opposite the tuyere, and only the "greillade" or small ore is subsequently added. In the American forge on the contrary, the ore, in a finer state of division is more or less continuously introduced, and the charging of a furnace after each operation is dispensed with. The blast employed has a pressure of one and a half to one and three fourths pounds ^{per} square inch and is heated to a temperature

varying from two hundred to two hundred and thirty degrees Centigrade, by being passed through iron pipes which are above the furnace and heated by the waste flames. The ~~daily~~ production, in twenty four hours, of one of these forges is about twenty-four hundred pounds.

The Slückoffen or High Bloomery Furnace.

In some parts of Europe an apparatus was formerly used which held a middle place between the low hearth of the Pyrenees and Corsica and the high blast furnace now adopted for the production of iron from its ores. These furnaces were called Slückoffen by the Germans, and by the French, fourneaux à pièce. These were, in fact, small cupolas, of which the height did not ordinarily exceed fifteen feet, and of which the diameter of the hearth was about three feet. This furnace was furnished with but one hearth, by which the tuyere was introduced, and the extraction of the bloom was effected. The blast was furnished by a water driven bellows. The slag escaped by a small floss-hole made at a certain distance above the bottom of the

hearth. To remove the Slück or bloom of spongy metal formed in the hearth, the bellows had first to be removed and a hole made in the masonry of the furnace, which was afterwards temporarily closed by a wall of brick and fire-clay. This furnace was charged with roasted ore and charcoal. After twenty-four hours a considerable mass of iron ~~had~~ accumulated. The sides of the hearth were now taken down and the mass removed by strong iron bars to a heavy hammer. The hammer reduced it to a cake about four inches thick, which was subsequently divided into two equal parts. These were afterward refined in a small bloomary of peculiar shape, where they were held by powerful tongs, exposed to the action of a flame from a nearly horizontal tuyere, by which means a portion of the metal flowed to the bottom of the hearth, where it accumulated in a spongy mass. This mass was drawn out into bars. A great quantity of charcoal was required by this process, and for this reason the method has fallen into disuse.

The rude furnaces, by increasing in size and by the application of a more and more powerful draft

grew slowly into the now familiar form of the present day blast furnace. The character of the product gradually changed, until it assumed the form now known as cast iron. At what period this revolution in iron making was complete is not known definitely. It is probable that cast iron was regularly made as early as the middle of the sixteenth century.

In sixteen hundred and nineteen, Dudley, a son of Lord Edward Dudley, succeeded in using coal as a substitute for charcoal. A patent was issued to Lord Dudley, and its date marks the beginning of a brief period of successful iron manufacturing. In sixteen hundred and fifty one, commercial difficulties drove Dudley out of business, and the use of pit coal ceased for nearly a century.

In seventeen hundred and six, Abraham Darby, acquired or rediscovered the art of making castings.

About seventeen hundred and thirty five, Abraham Darby, Junior, the son of the Darby just mentioned, made coke by treating it similarly to the manner in which wood is treated for charcoal, and successfully

substituted the coke thus made, for charcoal, and from that time ~~the~~ coke and coal have been used in increas~~ing~~ quantities.

In eighteen hundred and twenty-four, Neilson received a patent for a hot-blast stove to be used for forges and furnaces, and this change introduces the latest era in the history of this metal-- the era which precedes the age of steel.

The first furnaces of the indirect process were small, using cold blast, ^{and heating} charcoal as the fuel. The charcoal was used because of the impurities in the coke which went into the iron. Later the size of furnaces were increased and hot blast was used. Charcoal was abandoned for coke, ~~and~~ the supply of charcoal was small, and the compressive strength of charcoal ^{was} not ~~being~~ sufficient to stand the burdens of the modern blast furnaces.

A charcoal furnace nine feet in diameter and thirty two feet high, making fifteen hundred tons of iron per year with cold blast, represents the usual practice in the United States, ^{at} about eighteen hundred

and seventy five.

Figure three represents a warm-blast charcoal furnace. The charge is thrown from the charging floor a into the hopper b, where it rests upon the cone D. A lighted taper is thrown upon it to inflame gases which arise when the charge enters the furnace. Air is forced into the furnace ~~when the~~ ^{at a} pressure ~~reaches~~ ^{is} about two and a half pounds; and a temperature varying from five hundred and ninety to seven hundred and sixty degrees Centigrade. It enters through the tuyeres P, which are set in the tuyere arch ll. The tuyeres and arches are kept cool by circulation of water thro them, either in coiled pipes or in their hollow walls. The walls of the furnace are separated by a space J which is filled with water-worn sand, ordinarily called soil, or broken brick or refuse material of any kind that will not cake at the high temperature likely to exist there. The outer walls are usually built of red brick, and generally protected by a jacket of iron. The inner walls are made of fire-clay.

Figure four is a section of a charcoal furnace that has done good work.

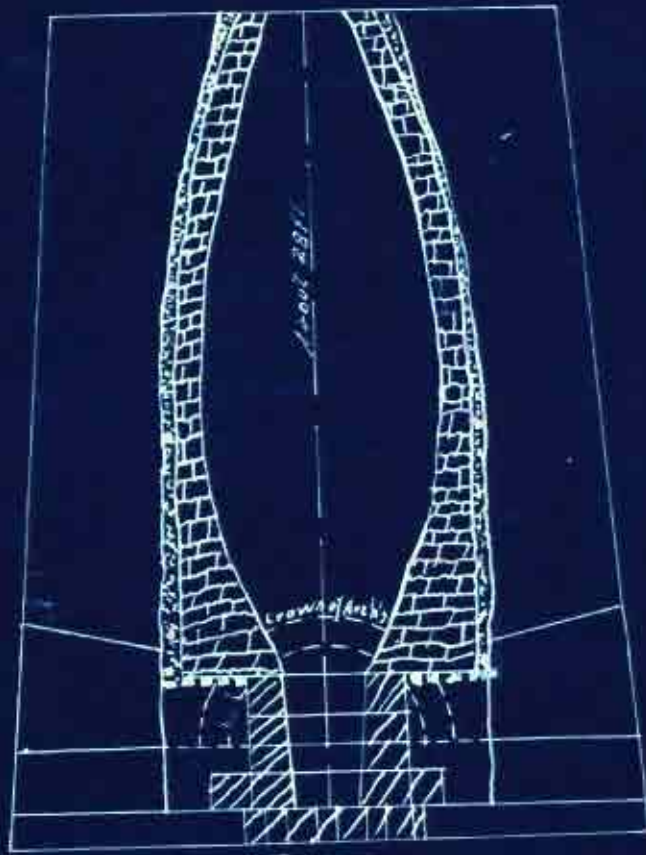


Fig 4

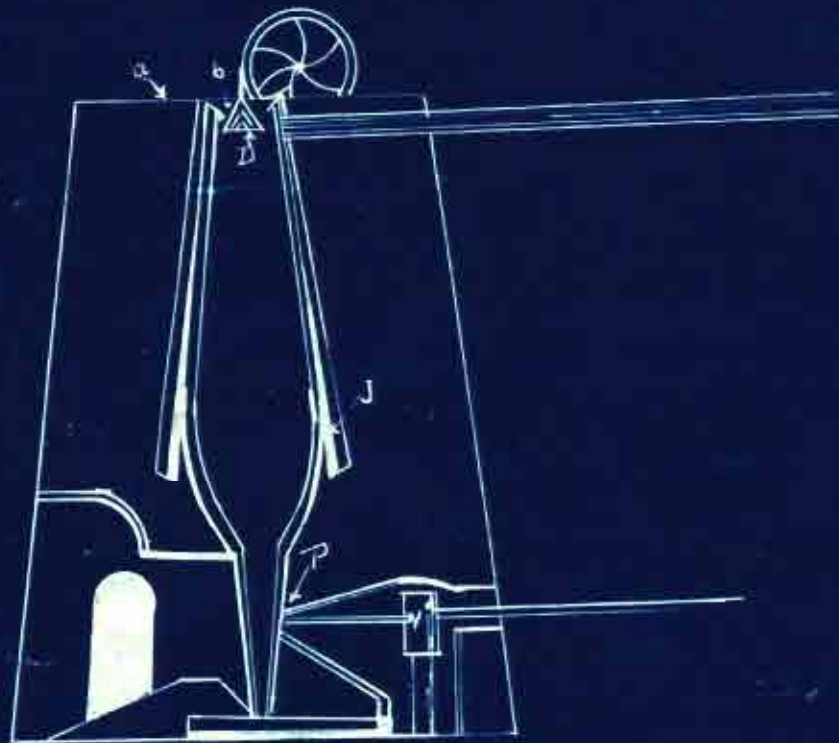


Fig 3

Figures five and six show vertical and horizontal sections through the hearth of a blast furnace in its most primitive form of a shaft or cavity formed of two truncated cones, joined together at their bases, with a cooling space in their walls.

The stack is formed by an interior lining of fire-brick, which is separated from the exterior coating by a casing of refractory sand or broken scoria. The throat is often surrounded by a chimney, in which there are one or more openings for charges. The external brick coating is supported by a mass of masonry, composed of either stone or brick.

Elliptical and rectangular furnaces have been tried, but do not, at the present time, seem to be in favor with blast furnace men. ^{The} Rackette Furnace is of rectangular type. It was first introduced in Russia and since then has been used in other parts of Europe. The oblong hearth emerges into a shaft which regularly, in size upward, increases, and which at the throat is from two and a half to three times as wide as the hearth. Figures seven, eight and nine represent

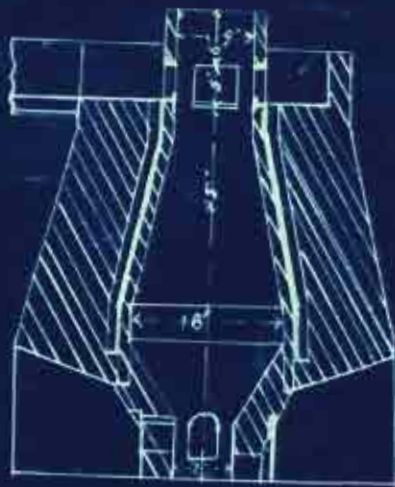


Fig 5

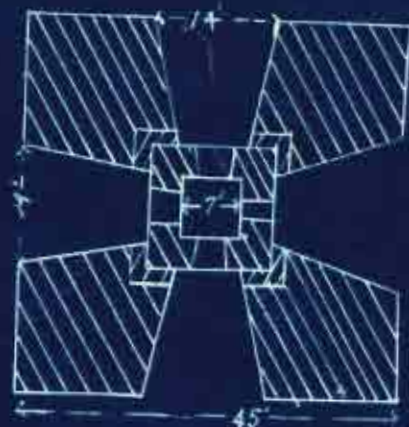


Fig 6

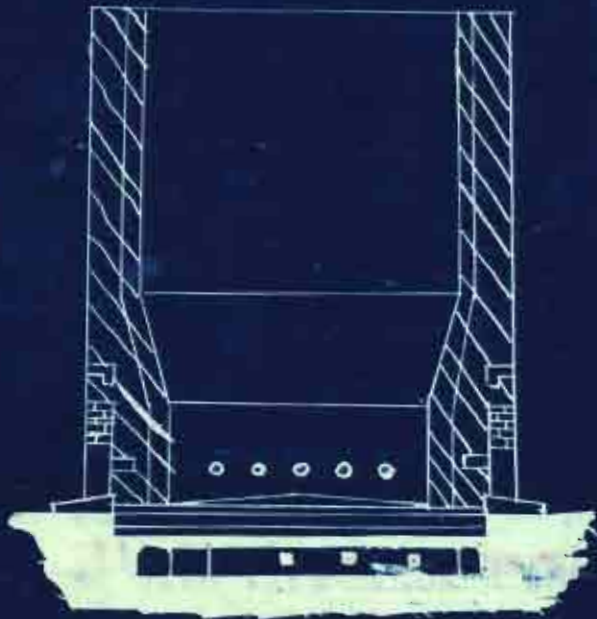


Fig 7

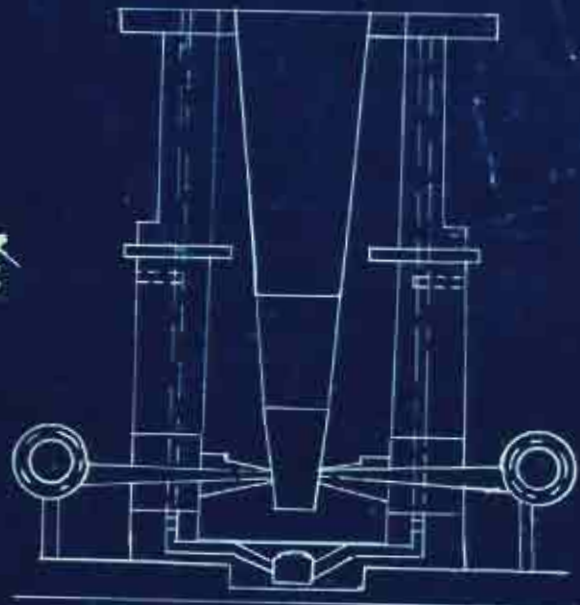


Fig 8

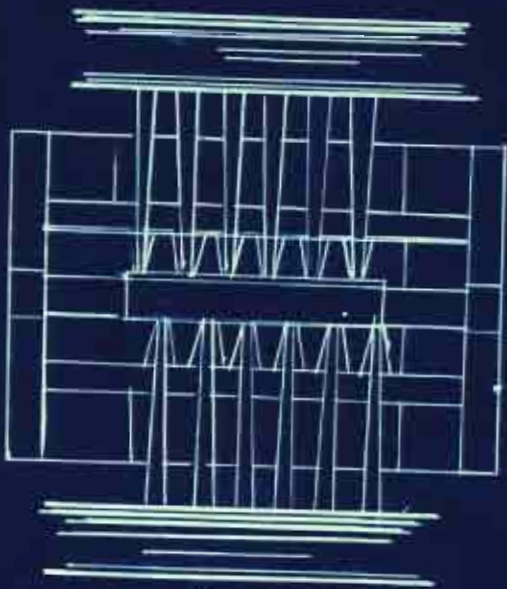


Fig 9

longitudinal, horizontal (above tuyere), and transverse sections of the Rackette Furnace.

We may now consider the progress which took place between eighteen hundred and fifty-four and eighteen hundred and seventy-four. Figures ten, eleven and twelve show this progress in design. Figures ten and eleven have no down-comer and the gases are waste, while in figure twelve the down-comer is used and the gases are taken to boilers and stoves.

A modern Cleveland furnace consists of an outer shell of wrought iron, rivetted together and resting on a ring which is supported on cast iron columns. It is lined with fire-brick slabs, and closed at the top with the cup and cone arrangement, which is now generally employed to allow of the collecting of the waste gases, and for proper distribution of the charge. This furnace is eighty five feet high, its internal capacity is thirty thousand cubic feet. The diameter at the base is twenty eight feet, and at the hearth eight feet, while that at the charging bell is thirteen feet. The blast is heated by two Cowper

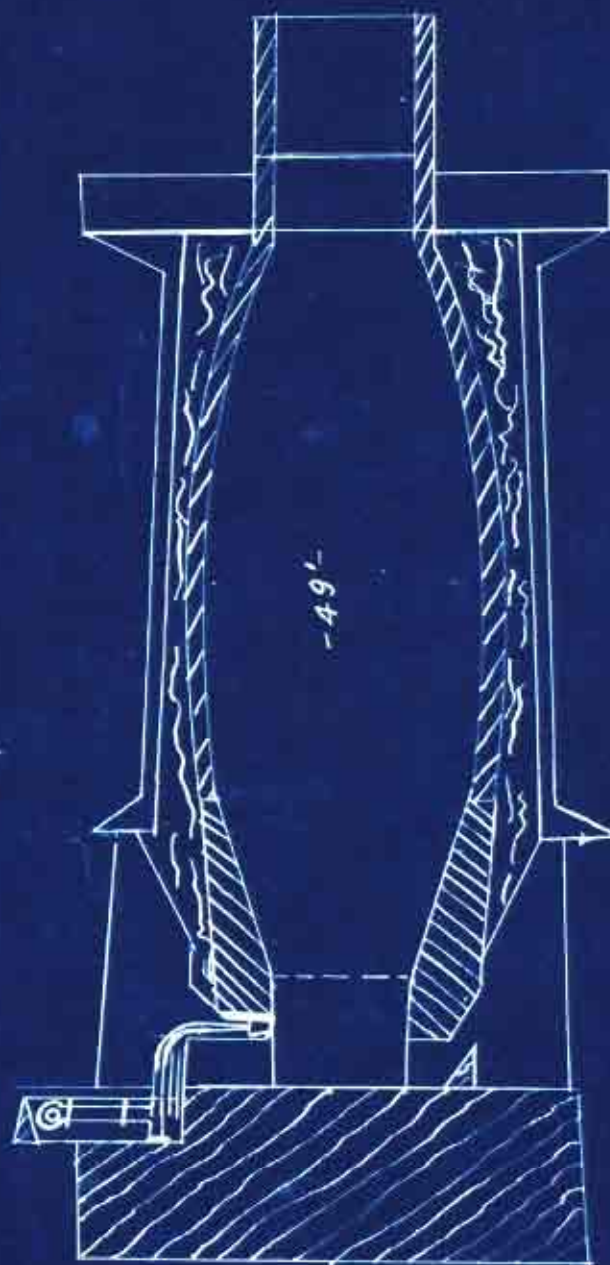


Fig 10

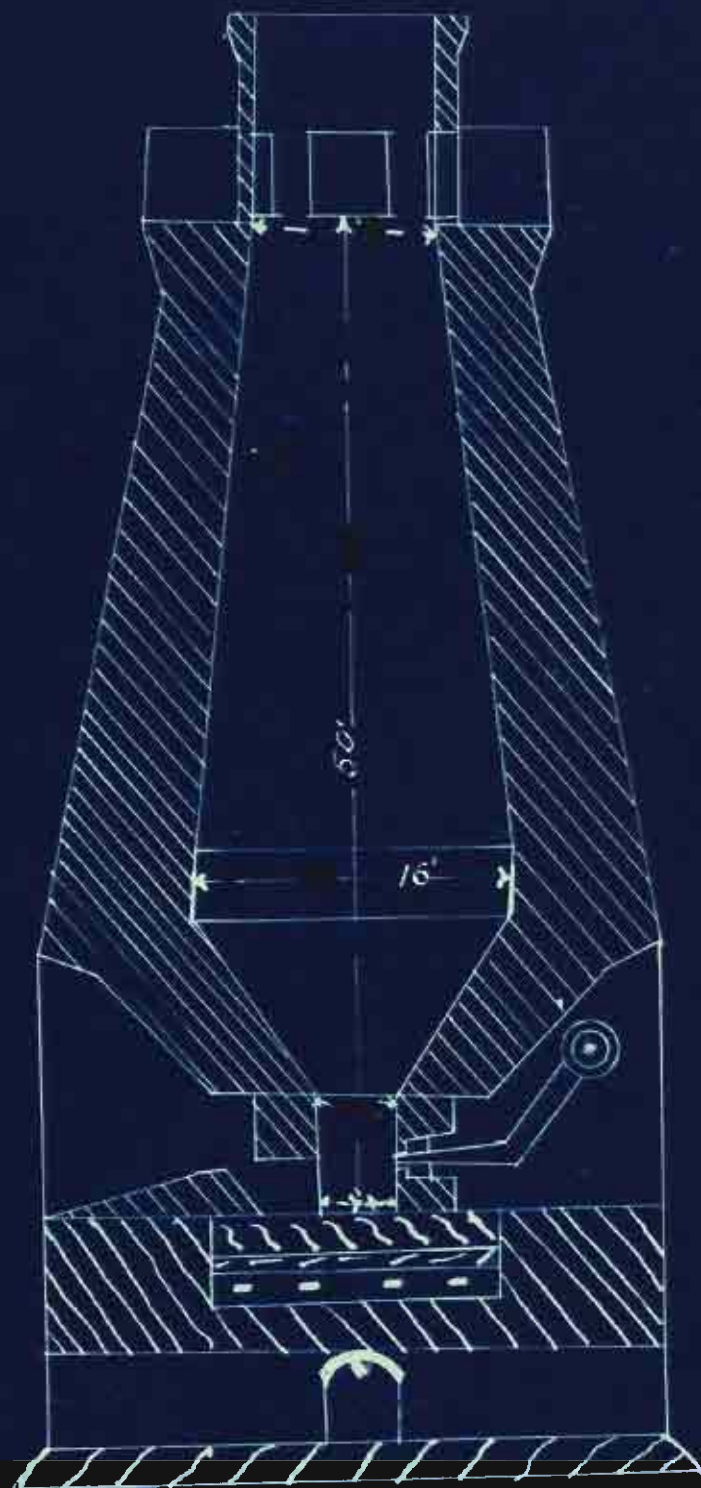


Fig 11

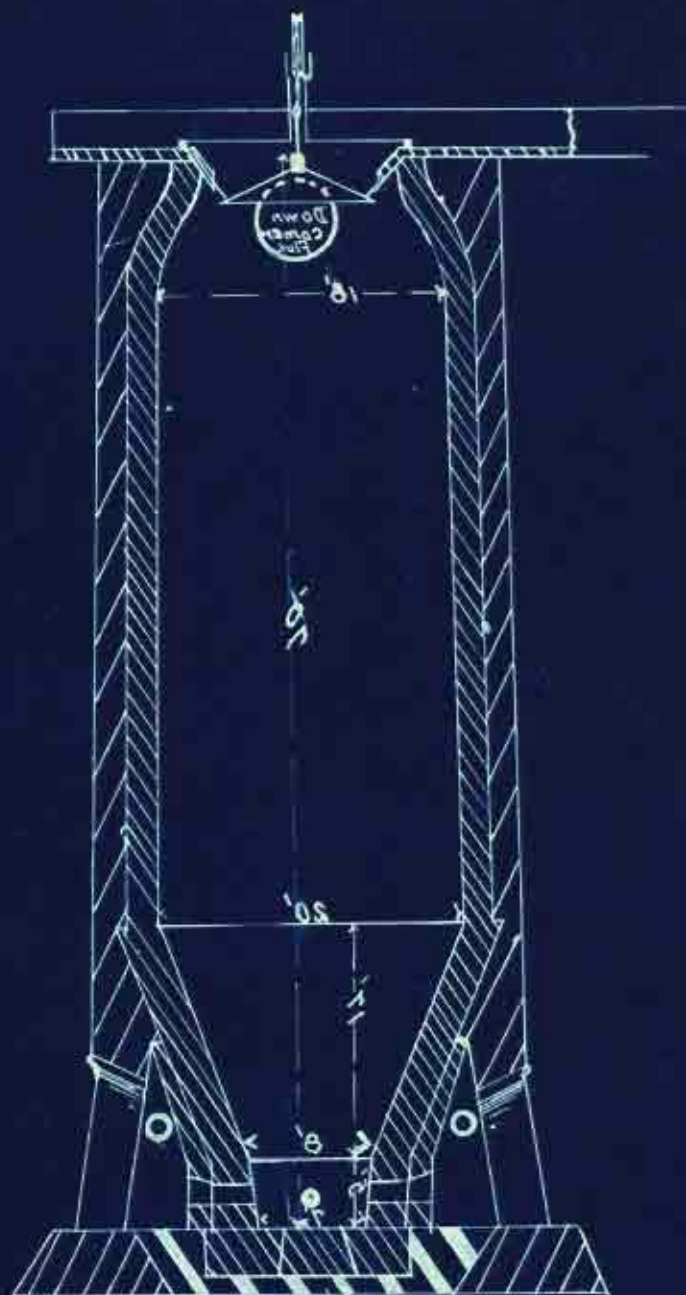


Fig. 15

Glass Furnace, Down Comer; vertical section

stoves for each furnace and enters through six tuyeres at a temperature of about fourteen hundred and fifty degrees Fahrenheit and a pressure of five pounds. The Cleveland ore employed contains slightly over thirty percent of metallic iron and is calcined before being used. About twelve C^WT of limestone is added for each ton of iron made, while about two thousand pounds of coke, containing seven percent ash, is required. The weekly output of such a furnace is about five hundred tons of pig iron, while seven hundred tons of slag would also be produced in the same time with the ore mentioned.

✓ As an example of the construction of a modern American furnace, that of furnace F of the Edgar Thomson Works is given. This furnace is supported in the usual manner on cast iron columns, upon which rest an annular ring. The shell of the furnace is supported on this ring. This shell consists of plates of wrought iron or mild steel rivetted together and lined with specially shaped slabs of fire-brick. The lines of the furnace may be divided into four parts

each represented in section by straight lines. The fire-brick may be therefore, more uniform in shape. The maximum internal diameter of this furnace is twenty two feet, the outer diameter being thirty feet. The diameter of hearth eleven feet, that of the charging bell twelve feet, and that of the throat fifteen and a half feet. The height is eighty feet and the cubical capacity is eighteen thousand two hundred cubic feet. The blast supplied is twenty five thousand cubic feet per minute, which enters through seven tuyeres at a temperature of eleven hundred degrees Fahrenheit. The pressure is from nine to ten pounds per square inch. The ore used is rich in iron, containing about sixty percent metallic iron; one thousand pounds of lime-stone and seventeen hundred pounds of coke are used per long ton of pig iron produced. The average weekly output of this furnace is twenty two hundred and eight tons.

Of the two furnaces it will be observed that the Cleveland or English furnace has the greatest internal capacity and the smaller hearth, it smelts a poorer

grade of ore, has a smaller weekly output, makes more slag, and consumes more coke per ton of pig produced. The original cost is somewhat less in the Cleveland, while the furnace runs about five times as long before requiring relining, so that the actual production of iron during the life of each furnace is about the same.

In order to retain the shape of boshes in furnaces which work rapidly, it has been found necessary to introduce water blocks or hollow iron castings thro which water circulates, in the brick work of the bosh. Four such are shown in the section of the Edgar Thomson furnace.

The modern tendency is toward a bosh angle of about seventy five degrees, tolerably low in the furnace. It seems that no one shape is best for a bosh line, but modifications are necessary according to the nature of the ore and the fuel. With rapid working and richer ores, a steeper bosh is permissible. It may be added that cylindrical furnaces that have been tried, always worked unsatisfactorily.

In designing a furnace it is unnecessary to avoid abrupt changes of angle, as a furnace will make its own internal lines in a short time of operation.

We may now make a summary of the design of a modern blast furnace taking each item up in brief detail.

The present shape of the iron blast furnace, shows a pair of truncated cones set end to end. This shape has been reached in part experimentally and in part by reasoning. Some would refer the shape of the furnace to the mechanical variations of the charge; others to the need of having the rising gases pass evenly through different parts of each horizontal section, and others to the variation of the volume of gas in different parts of the furnace. No doubt all of these items are important and must be considered. The larger unit offers the advantages of economizing in installation, in labor, in administration, and in lessening the amount of outer heat wasting surface per ton of product.

The conditions which limit the size of furnace will next be considered. Fearing the blast would not

penetrate to the center of the charge, the width to tuyere has been limited to twelve and a half feet. The width of the hearth of the Lackawanna furnaces have been increased to seventeen feet and have worked successfully. In this event the furnace may be widened all the way from top to bottom and rate of production increased greatly.

With the hearth diameter at twelve and a half feet, the furnace designer tries to gain volume by widening his furnace as abruptly as possible, hence the boshes are made as flat as possible. In practice, the angle which the boshes make with the horizontal must not be less than seventy three degrees, and seventy six is a more usual angle. If boshes were more flattened, the material descending would not slide freely over them, as the lower end is gradually eaten away by the burning of the coke. We must bear in mind that lower part of furnace contains only solid coke, the rest of the products melting at about twelve feet above the tuyeres. Too steep a bosh, that is, eighty one degrees, tends to lead the rising gases in undue proportions

along the wall and too little through the descending column of solids, consequently axial ore may reach lower parts of furnace insufficiently reduced, thus causing unevenness of working. With a seventy six degree bosh, the charge descends only as lower portions are eaten away, since the flattening causes jamming, which allows coke to descend only as far as the lower end becomes free. With the latter bosh angle the coke is not allowed to dip into the molten slag or metal, which prevents the variation which would occur in case of steep bosh where amount of coke immersed varies according to conditions. The coke immersed in the metal or slag acts energetically on them.

In the very swift running furnaces of the Pittsburgh district, the outer slope of the boshes stops short at about twelve feet above the tuyeres. The reasoning of this is that at this level the descending charge reaches a temperature at which it begins to melt and become pasty. If the height of bosh were carried higher, this pasty grout^e would tend to arch, so ^{we} must continue outward flare, to ^a point

where charge begins to melt, then begin\$ to contract.

It is fundamental that the charge shall be distributed evenly over the top of the furnace. In practice the throat diameter is rarely over sixteen feet. On the other hand, narrow tops restrict the room for passage of the gases, causing a high velocity and thereby carrying over much fine material.

The walls pass downward from the top with an outward batter of six to nine or more degrees. This batter eases the descent of the charge which here is obstructed by the rapid deposition of carbon on the ore. The batter at the different levels should be arranged to best suit the conditions at that zone, but at the present time this is not done.

The height is limited usually to one hundred feet, and probalby better to eighty feet. If height of furnace is increased to get a greater capacity, this means a greater volume of air blown through, which means a mach higher blast pressure as the velocity of the gases must be increased. Also the material in the furnace will be packed harder, causing the interstices to become smaller which further increases the

resistance to the passage of the gases. It seems that if our present capacity of furnaces is increased, it will be through increasing the diameter and not the height.

The conclusions to be drawn from the fore-going for a modern furnace are;

- (1) The height shall not be over one hundred feet, and better about eighty feet.
- (2) The batter from the top downward shall not be less than six, nor more than eleven degrees, and best about nine degrees.
- (3) The diameter at the top shall be between ten and sixteen feet.
- (4) The angle of boshes shall be seventy six degrees, and carried up (in a fast working furnace making a calcareous slag) not higher than twelve feet.